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Discussion on the article by Zhang & Meng entitled "Probabilistic ship domain with applications to ship collision risk assessment" [Ocean Eng. 186 (2019) 106130]

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1. Introduction

Safety is and must always be one of the most valuable properties of every system or a process. Any deviation from the safe state of the course of action must be recognized and the operator informed. Otherwise the developing situation will lead to losses - sooner or later. It is therefore of utmost importance to commit significant research resources investigating ways in which safety can be monitored and ensured.

The recent work of (Zhang and Meng, 2019) on maritime navigation safety is clearly heading in this direction, providing ideas and models that are superb inspiration for future work.

Although Zhang & Meng produced a significant contribution to the concept of ship domain by applying probabilistic rules and maritime traffic data, there are several inconsistencies within their work. These may affect the final results, and significantly limit the applicability of the proposed domain in navigation operations, as anticipated by the Authors.

Their paper claims that the newly developed ship domain can be used for navigation operations, in order to enhance ship safety. However, we would like to refer to three major assumptions made in the mentioned paper, that result in the ship being at stake, if the concept is applied as onboard navigation solution in real life.

2. Problem statement

2.1. Safety critical distance

In order to develop the probabilistic ship domain, Zhang & Meng analyzed the critical ship safety distance (CSSD), which they defined as the smallest distance during the encounter of two ships, as illustrated in Fig. 4 of the commented paper. In maritime nomenclature such distance is usually referred to as CPA (distance to the closest point of approach). However, it is not clear from the commented paper why such distance shall be considered critical.

To make judgment about any physical quantity a reference to some standard needs to be made in a first place. Based on the relation between measured quantity and the standard, a statement about the former and a situation it describes, can be made. In the case of passing distance, being the measured quantity, the standard can be either objective, like minimum required maneuvering distance for a ship on a collision course, or subjective like distance imposed by safety management code adopted in a given shipping company, based on best practices.

Subsequently, if in the course of an encounter the passing distance is equal or less than the adopted standard, then obviously such a situation can be considered critical and unsafe.

Moreover, the analysis presented in the commented paper is based on one-week AIS data, without information on any critical encounter spotted during that time, thus the distances recorded most likely refer to normal and safe encounters, rather than critical situations.

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Therefore, in our view, there are no grounds whatsoever to refer such recorded distances as critical.

2.2. Risk of collision

In section 2.1 of (Zhang and Meng, 2019), the Authors state that if the distance between the own ship and a target is greater than 2 nautical miles (NM) there is no risk of collision *"l(theta) is a given non-negative value and is set to* 2 NM*, which is the safe distance beyond which the target ship is not considered as a threat from the perspective of ship collision*". The statement is based on a reference to another paper by (Dinh and Im, 2016), which sadly but most probably have been misunderstood. In the latter, it is said that *navigators define that the safety range for avoiding other vessels depends on the size of target ships and typically is* 2NM *in normal conditions by their habit* (sic!). The difference is that navigators usually **wish to keep** all other vessels outside 2 NM radius from the own ship or, in other words, maintain a minimum 2 NM CPA, as a result of effective collision avoidance maneuvers. This value varies depending on one's habits, self-confidence, traffic density, weather conditions, etc., see for example (Bole et al., 2014; Cockroft and Lameijer, 2012).

Therefore, motion parameters of a target involved in an encounter should be assessed **before reaching** the set limit. Once within the limit, the close-quarters situation occurs, and different rules shall be applied with a necessity to execute direct actions to avoid the imminent collision. These shall be in compliance with the COLREG rules describing actions of a stand-on vessel, provided that ships are in sight of one another - (Rule 17 a) ii) and b)). Thus, the distance considered as dangerous and relevant for analyzing AIS targets should be somehow related to COLREGs (IMO, 2003). This could allow for keeping the limits of the traffic analysis reasonable from an operational point of view. One of the possible solutions is to set the limit to 3 NM, which refers to the required minimum visibility of sternlight, as well as sidelights (as per Rule 22 a)). This requirement concerns vessels larger than 50 m in length, which comprise the vast majority of the worldwide merchant ocean-going fleet.

Moreover Zhang & Meng also assert, following (Debnath and Chin, 2010), that there is no collision risk if the target ship is outside of the own ship's domain, which in the commented paper (Figs. 10–12) is smaller than the 2NM limit. Otherwise, Authors claim, the collision risk exists, and gradually increases towards 1 at a very short distance from the own ship to the target.

The COLREGs - specifically its Rule 7 - *Risk of collision* reads as follows: "*Risk of collision shall be deemed to exist if the compass bearing of an approaching vessel does not appreciably change*". Therefore, the collision risk begins to exist regardless of the distance between two encountering ships, as long as the conditions laid down by COLREGs are met. Besides, risk of collision accounts for wider set of parameters than the distance alone, these have already been extensively described in the literature (Baldauf et al., 2011; Goerlandt et al., 2015; Sotiralis et al., 2016; Szłapczyński and Śmierzchalski, 2009; Zhang et al., 2018, 2016, 2015). The foremost condition for the encounter to be considered dangerous is the spatio-temporal layout of the vessels potentially leading to close-quarters situation. Distance alone is not enough to judge about the safety of the encounter.

Thus, we find the justification for labelling risk zero or one just because of the distance between two encountering ships as void.

2.3. The target to consider first

Furthermore, Zhang & Meng state in their paper the following "*It should be noted that the captain of the own ship only cares about the status of the nearest ship in one direction which is the most serious threat to its safety*". Leaving aside the fact that it is not always the captain of the ship who is in command, the whole statement needs clarification. First, the target to be considered as posing a threat to the safety of the own ship should be on a collision course or close to it. Otherwise, even if the target navigates at close distance it may pose negligible risk to the own ship. Second, as per Rule 8 c) of COLREGs, any action to avoid collision must be executed in such a way that it *does not result in another close-quarters situation.* It means that not only the closest vessel must be observed, but also the movements of other objects in the vicinity must be monitored, (Ożoga and Montewka, 2018). Third, in day-to-day marine navigation the officer of the watch adopts various techniques for collision avoidance, however one common approach is to deal first with that collision target that is the soonest, see (Bole et al., 2014), rather than the closest, since that one will arrive in close-quarter situation as the first. In seagoing practice, this is usually achieved through a verification of the TCPA value (time to CPA), for an object considered as a potential threat.

Therefore, the statement on the closest target being the most hazardous remains void.

3. The use of ship domain in collision avoidance

Finally, to answer the question whether the proposed domain can be used for day-to-day ship navigation and risk assessment in ship-ship encounters, we use the following example.

In an encounter of two container vessels of the same size, when they are on a collision course proceeding with the speed of 20 knots towards each other, the own ship requires some area to perform evasive maneuvers. For the purpose of this example let us call this area the minimum maneuvering space (MMS). The calculated MMSs are depicted in Fig. 1 as envelopes, obtained with the use of complex ships encounters simulator employing six degrees-of-freedom numerical ship motion model, see (Gil et al., 2020, 2019). The depicted envelopes are calculated for predefined collision scenarios of two container ships belonging to the post-Panamax C-11 class (262 m in length between perpendiculars). The red envelope indicates the area determined for a set of scenarios where two ships proceed at the same speed of 20 kts. The green

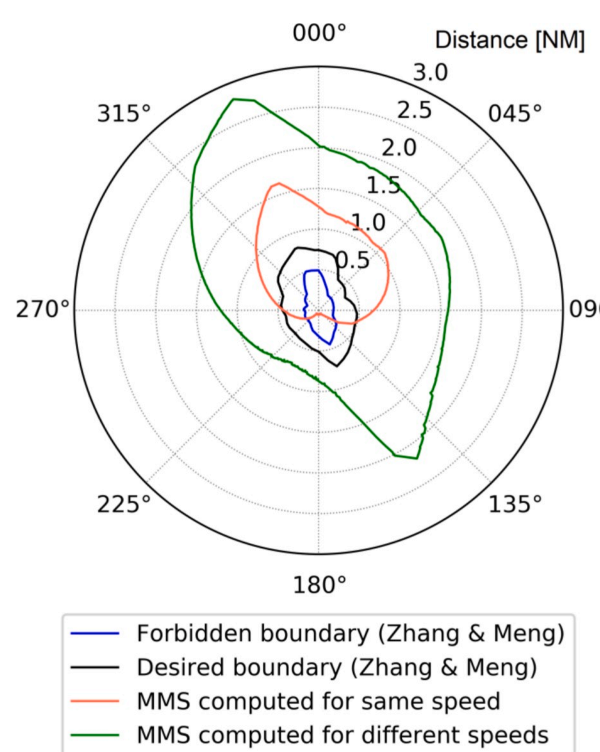

Fig. 1. Overlay of two types of area: 1) required minimum maneuvering space (MMS) for different encounter scenarios of two C-11 container ships proceeding with same (red) and different (green) speeds; 2) probabilistic domain with forbidden boundary as presented in (Zhang and Meng, 2019) rescaled to the length of C-11 container ship. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

envelope delimits the area obtained for the scenarios where the target ship proceeds twice faster (20 kts) than the own ship (10 kts). In both cases own ship executed an evasive maneuver by setting rudder hard to starboard (rudder angle $+30^{\circ}$), while target ship maintained her course and speed. The performed simulations do not account for the weather conditions.

The envelopes of both determined MMS delineates the area that **must be kept free** from any other objects on collision course, otherwise it is not possible to escape from the collision by the own ship manouvers alone. In other words, the probability of collision between the own ship and a target that is on a collision course, resides within MMS, and does not perform collision evasive manoeuver, equals one. Similar area is defined by Zhang & Meng within their domain, referred to as *forbidden area,* which is "(...) *extremely dangerous and the probability of target ships navigating in is zero"*.

However, as can be seen in Fig. 1, the domain, including forbidden area, sits well within the MMS, being significantly smaller than the MMS. This shows, that the situations which are marked safe by the domain - all the targets being outside the domain - can be already unsafe for the targets are on collision course. Therefore the presented domain seems to underestimate the safety for the targets on collision course and shall not be used for collision avoidance as presented in Zhang and Meng (2019).

4. Concluding remarks

Despite the significant contribution to the field of ship domain studies brought by Zhang & Meng with their recent study, their probabilistic domain cannot be expected to assist a navigator in his/her daily routine. Moreover, if applied in navigation it may seriously mislead the navigator, by considering safe all ships residing outside the own ship domain, without any further information on the relation between targets' and the own ship's motion paramters. This has been illustrated by the example above.

In light of the above, it is important to remind the anticipated application areas of ship domains, as originally suggested by Fujii and Goodwin back in 1970s (Fujii, 1970; Fujii and Tanaka, 1971; Goodwin, 1975). Fujii in his paper claims that the concept of ship domain can be used to determine the maximum traffic density of a waterway. Whereas Goodwin sees the following additional application areas for her concept: external control of sea traffic, encounter rates, computer simulation models. Obviously neither of the domains is seen applicable for supporting process of ship navigation and collision avoidance, since the domain does not delineate safe from unsafe encounters. Rather it shows the preferences of navigators with respect to the distance at which they wish to pass with other targets **after** the successful collision avoidance action has already been performed.

Unfortunately, this original message from the domains' developers seems to have been forgotten over the years.

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